A STUDY OF THE POLARIZATION OF THE LIGHT EMITTED BY INCANDESCENT SOLID AND LIQUID SURFACES. II.

By R. A. Millikan.

X.

Application of Fresnel's Formulæ for Vitreous Reflection.

THE main object of this research being to determine whether or not polarization by emission could be experimentally proven to be a phenomenon of refraction, Fresnel's laws for reflection and refraction, which have been shown by many experiments to accurately represent the facts, were now applied to the determination of the amounts of polarization which should be produced by single refraction of light passing through the boundary surface between uranium glass and air. In order to apply these laws it is necessary to assume that all of the light emitted by the uranium glass, whether coming *from the surface molecules or from the interior layers*, has undergone the process of refraction — an assumption not contained in Arago's explanation of the cause of the phenomenon.

Taking the intensity of the incident ray as unity, Fresnel's formulæ give for the intensities of the reflected and refracted rays when the incident beam is plane polarized in the plane of incidence,

$$\text{reflected ray} = r_1 = \frac{\sin^2(\alpha-\beta)}{\sin^2(\alpha+\beta)},$$

$$\text{refracted ray} = r_1' = \frac{4\cos^2\alpha\sin^2\beta}{\sin^2(\alpha+\beta)},$$

α being the angle of incidence and β the angle of refraction.

For a ray plane polarized in a plane perpendicular to the plane of incidence

$$\text{reflected ray} = r_2 = \frac{\tan^2(\alpha-\beta)}{\tan^2(\alpha+\beta)},$$

$$\text{refracted ray} = r_2' = \frac{4\cos^2\alpha\sin^2\beta}{\sin^2(\alpha+\beta)\cos^2(\alpha-\beta)}.$$

Since ordinary light may be considered as composed of two equal plane polarized beams, polarized in planes at right angles to each other, the amount of polarization in a beam of natural light which has undergone single refraction is

$$\frac{\frac{1}{2}r_2' - \frac{1}{2}r_1'}{\frac{1}{2}r_2' + \frac{1}{2}r_1'} = \frac{\dfrac{1}{\cos^2(\alpha-\beta)} - 1}{\dfrac{1}{\cos^2(\alpha+\beta)} + 1} = \frac{1-\cos^2(\alpha-\beta)}{1+\cos^2(\alpha+\beta)} = p.$$

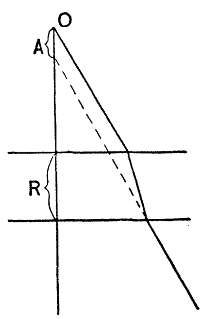

FIG. 4.

The only unknown quantity in this formula is the angle β. In order to determine p for any given angle it was only necessary to determine the index of refraction of the uranium glass.

The glass being of considerable thickness, the microscope method was the one best adapted to this determination. d being the thickness of the glass, and a the change in focus due to the introduction of the glass between the object O and the objective, the index u is given by the formula (see Kohlrausch, *Praktische Physik*, p. 151),

$$u = \frac{d}{d-a} = \frac{326\text{ mm.}}{326\text{ mm.} - 110\text{ mm.}} = 1.51 = \frac{\sin\alpha}{\sin\beta}.$$

The substitution of the various values of β, thus found, in the formula for p gave the following values: —

α	β	p	p (observed)
87° 30′	41° 25′	0.351	0.358
85°	41° 17′	0.315	0.293
80°	40° 42′	0.251	0.245
75°	39° 46′	0.206	0.191
70°	38° 29′	0.153	0.139
65°	36° 53′	0.125	0.098
50°	30° 29′	0.058	0.039

The correspondence between the results given by experiment and those given by this calculation from Fresnel's formulæ was unexpected. The experiments were completed more than a month before any calculations were made, so that I had no idea at the time of making the experiments what would be the nature of the results given by calculation.

The differences between the two sets of values are hardly greater than the possible errors of observation. The differences at 65° and 50° are quite large, but might have been due to the lack of perfect uniformity in the luminous surfaces. On the whole, the agreement between the two sets of results indicates strongly that in the case of uranium glass, at least, the phenomenon is one of simple refraction at the surface; but that the WHOLE *of the emitted light undergoes the refraction process.*

XI.

Experiments upon Platinum.

It is evident that no such comparisons as those just made for uranium glass could be made for the case of incandescent metals, unless, in the first place, the surface experimented upon could be assumed to be a perfectly definite, non-diffusing surface. The chief source of difficulty in the work upon platinum was to fulfil this condition.

It was found, after considerable work had been done upon platinum, that continual heating roughened the surface to a slight degree, and changed the amount of polarization. The results of several sets of laborious observations upon platinum were discarded altogether, because they were found to be erroneous from this cause. However, the change is so gradual that a well-polished platinum surface may be heated to incandescence for several minutes without showing any perceptible change in character. The rapidity of the change could be delicately observed by viewing the surface at a large angle of incidence by means of the polarimeter. For a period of two or three minutes no change was perceptible in the equality of the images, but for much longer periods of heating the slow blistering of the surface began to be manifest in the disturbance of the equality of the images. Hence, in order to avoid this error, the surface of the platinum was carefully polished with rouge after every set of readings for a given angle.

A second slight source of error in the observations upon platinum was the lack of exact horizontality in the surface examined. The attempt was made to avoid this error by rotating the instrument through 90° according to the suggestion of Cornu. This brought the extraordinary image either above or below the ordinary; hence, when the angle of emergence was very large, the two images corresponded to points on the surface at a considerable distance from each other, as shown in the figure.

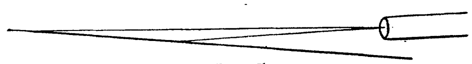

FIG. 5.

This introduced the likelihood of a much greater error than that due to a slight error in horizontality. The incandescent platinum was therefore rendered as nearly horizontal as possible by comparison with carefully leveled reference planes placed in the immediate vicinity. The adjustment could thus be easily made to within one degree.

In all of the following experiments sheets of rolled platinum 0.06 mm. in thickness were heated to a white heat by means of a Bunsen burner, care being taken to prevent light from any other sources from vitiating the results. The observations are here given in full.

80°		70°		60°	
Left.	Right.	Left.	Right.	Left.	Right.
23.1	12.0	30.2	20.7	36.9	24.5
21.4	11.5	32.2	21.0	36.8	26.1
22.5	11.3	32.1	21.2	35.0	25.0
22.3	10.9	31.0	20.5	37.0	25.4
23.2	11.4	32.1	21.3	35.6	25.5
				35.5	25.4
22.5	11.42	31.52	20.94	36.05	25.2
$2w = 34^\circ.0$		$2w = 52^\circ.4$		$2w = 61^\circ.25$	
$p = 0.829$		$p = 0.610$		$p = 0.481$	

50°		40°		30°	
Left.	Right.	Left.	Right.	Left.	Right.
40.0	29.7	45.6	35.0	47.6	38.0
39.1	29.0	45.5	33.3	47.5	36.3
41.2	29.3	44.4	34.2	47.2	36.2
39.4	28.5	43.8	34.6	47.8	37.1
41.0	29.6	44.4	34.5	48.0	36.0
40.14	29.2	44.74	34.3	47.62	36.72
$2\,w = 69°.34$ $p = 0.349$		$2\,w = 79°.0$ $p = 0.191$		$2\,w = 84°.34$ $p = 0.099$	

XII.

Application of Cauchy's Formulæ for Metallic Reflection to the Case of Platinum.

Fresnel's formulæ for reflection rest upon the hypothesis that the time required in the process of reflection is infinitesimal in comparison with a wave period, and hence that the phase of vibration of the reflected ray is either the same as that of the incident ray, or else differs from it by the quantity π. It follows from this assumption that the reflected ray is plane polarized, if the incident ray is plane polarized.

When the reflection takes place at the boundary surface between air and a metal, experiment shows this assumption to be incorrect, and hence Fresnel's formulæ become inapplicable.

If the phenomenon here considered be due to reflection, the laws for reflection which apply to the boundary surface between platinum and air are, of course, the laws to apply to the determination of the amounts of polarization which ought to be caused by a single refraction at this boundary.

The application of Fresnel's laws of vitreous reflection requires, as has been seen, the determination of but one constant, the index of refraction, or the ratio of the velocities of propagation of light in the two media. Cauchy extended these laws so as to cover the case of metallic reflection by introducing another constant which he calls the coefficient of extinction. The constant corresponding to the index of refraction is, as in the case of transparent bodies, the tangent of the angle of maximum polarization. The coefficient of extinction is a constant depending upon the opacity of the body, and is found from the ratio between the amplitudes, after reflection, of two equal beams polarized respectively perpendicular and parallel to the plane of incidence, and reflected at the angle of maximum polarization. This ratio is evidently the tangent of the azimuth of re-established plane polarization, when the incident beam is polarized in a plane making an angle of 45° with the plane of incidence, plane polarization being re-established after reflection by means of a quarter-wave plate or a Babinet compensator.

This angle may be determined by experiment. Thus the two constants of metallic reflection are, (1) the angle of maximum polarization, and (2) the azimuth of re-established plane polarization at this angle. According to the theory of Cauchy, these two consonants being known, the intensity of a beam reflected at any angle may be calculated.

The complete explanation of Cauchy's theory and the deduction of Cauchy's formulæ were given by Eisenlohr in 1858. (See *Pogg. Ann.* 104, p. 368.)

The final forms of the formulæ given by Eisenlohr are

$$K^2 = \tan\,(f-45^\circ),\quad K'^2 = \tan\,(g-45^\circ), \tag{1}$$

in which K^2 is the intensity of the reflected beam when the incident beam is polarized in the plane of incidence, K'^2 the intensity when the incident beam is polarized in the plane perpendicular to the plane of incidence, and f and g are variables given by the equations

$$\left.\begin{aligned} \cot f &= \cos\,(e+u)\sin\left(2\arctan\frac{c\theta}{\cos a}\right) \\ \cot g &= \cos\,(e-u)\sin\left(2\arctan\frac{\cos a}{c\theta}\right) \end{aligned}\right\}, \tag{2}$$

in which u and c are variables determined by the relations

$$\left.\begin{aligned} \cot\,(2u+e) &= \cot e\cos\left(2\arctan\frac{\sin a}{\theta}\right) \\ c^2 &= \frac{\sin 2e}{\sin\,(2u+2e)} \end{aligned}\right\}, \tag{3}$$

in which a is the angle of incidence and e and θ are given by the final formulæ

$$\left.\begin{aligned} \sin 2e &= \tan^2 A \sin (4H - 2e) \\ \theta &= \sin A \sqrt{\frac{\sin 4H}{\sin (4H - 2e)}} \end{aligned}\right\}. \tag{4}$$

A is the angle of maximum polarization, called the "principal angle of incidence," and H is the azimuth of re-established plane polarization when the incident beam is polarized in the azimuth 45°. H is called the "prime azimuth." The forms here given for e and θ are due to Jochman (see *Pogg. Ann.* CXXXVI., p. 856). These formulæ, first published by Cauchy in 1839, were shown by Jamin, by an elaborate series of measurements, to very closely represent the facts of reflection from metallic surfaces. The prime angles of incidence and the prime azimuths for all the common metals and for the different Fraunhofer lines were determined by Quincke in 1874 (see *Phil. Mag.* XLVII., p. 221).

Now, in order to apply these formulæ to calculations similar to those which have already been made with Fresnel's formulæ upon uranium glass, it was necessary to assume, as before, that the whole of the light emitted had undergone refraction, and it was also necessary to know the two optical constants for platinum at the temperature of incandescence. These constants could not be determined. However, in a number of experiments made by W. R. Grove (see *Phil. Mag.* (4) 17, p. 177) upon the reflection of light from incandescent platinum, he was unable to detect any change in the reflecting properties of the platinum due to the fact of incandescence. Plane polarized light being reflected from the cold surface, the plane of polarization of the reflected beam was not affected by heating the platinum to the incandescent temperature. These experiments were not performed with delicate apparatus, yet they give reason to assume that the optical constants of platinum are not greatly altered by temperature.

Assuming, then, the values of A and H given by Quincke for the sodium line, the calculations of the amount of polarization in the emitted beam were made for all the angles of emergence for which experiments had been made. These calculations were made as follows: —

Quincke's values for the D line are

$$A=77^\circ\ 8',\ H=32^\circ\ 46'.$$

Formulæ (4) give

$$e=64^\circ\ 22',\ \log\theta=0.62276.$$

Then for $a=80^\circ$ formulæ (3), (2), and (1), give

$$K^2=0.9348,\ K'^2=0.4013.$$

Assuming now the incident beam to have had an intensity unity, the emitted beam polarized in the plane of emergence would have an intensity

$$1-K^2=0.0652$$

and the beam polarized in the plane perpendicular to the plane of emergence an intensity

$$1-K'^2=0.5987.$$

Therefore the degree of polarization $=p=\dfrac{0.5987-0.0652}{0.5987+0.0652}=0.834.$

The complete results of the calculations for the platinum are as follows: —

a	K^2	K'^2	$1-K^2$	$1-K'^2$	p
80°	9348	4013	0652	5987	0.834
70°	8757	4044	1243	5957	0.655
60°	8234	4813	1766	5187	0.492
50°	7782	5483	2218	4517	0.341
40°	7409	5981	2591	4019	0.216
30°	7115	6330	2885	3670	0.117

Considering the number of assumptions which have been made, the correspondence between these quantities and those given by experiment is altogether remarkable, and points with as much certainty as the work upon uranium glass to the conclusion that the phenomenon is simply one of refraction.

XIII.

Difference in Color of Images.

In the course of these observations upon platinum, another at first unaccountable phenomenon was noticed. At large angles of emergence the color in the two images was notably different. The image corresponding to the component polarized perpendicular to the plane of emergence was markedly redder than the other.

If we assume the phenomenon to be due to reflection and refraction, this appearance is readily explained by a reference to Quincke's values for the angles of maximum polarization for the different Fraunhofer lines. This angle for the line C, Quincke gives as 78° 28′, and for the line G his value is 73° 39′. Now if a is the amplitude of vibration in the reflected ray when the incident beam is polarized in the plane of incidence, and a' the amplitude when the plane of polarization of the incident beam is perpendicular to the plane of incidence, the angle of maximum polarization will be reached when $\frac{a^2-a'^2}{a^2+a'^2}$ is a maximum, *i.e.* when $\frac{a'}{a}$ is a minimum. The experiments of Jamin show that this angle coincides, at least very nearly, with the angle for which a' is a minimum; a conclusion which one would expect without the aid of experiment. Hence the angle 78° 28′ is that angle for which the component of the *reflected* vibration parallel to the plane of incidence is a minimum for the case of *red* light, and the component of the *emitted* vibration in the same plane is a maximum. On the other hand, the angle of maximum emission of *violet* light in this plane occurred at 73° 39′. Accordingly, it is evident that red light predominates in the beam emitted at the angle 78° 28′, and violet in the beam emitted at 73° 39′. The approximate ratio between the two colors for any angle is shown in Fig. 6. It is evident that light emitted at any angle larger than 75° will be predominantly red. At the same time, the shape of the curves accounts for the lack of any noticeable predominance of violet in the neighborhood of 73° 39′.

The figure shows the curves of intensities of the reflected components of vibration parallel to the plane of incidence as roughly plotted from the values given above. The lines mD, m_1D_1, etc., represent the intensities of the emitted red vibrations in this plane for various angles; while the lines nD, n_1D_1, etc., represent the intensities of the emitted violet vibrations for the same incidences. The lines nM, n_1M_1, etc., are the measure of predominance of red over violet, or *vice versa*. The steepness of the curves at points corresponding to angles greater than the angle of maximum polar-

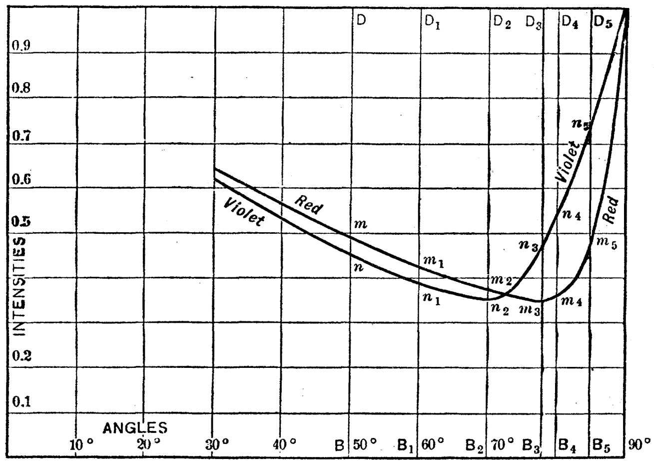

FIG. 6.

ization, and the lack of steepness at points corresponding to angles less than the angle of maximum polarization are evidently the causes of the predominance of red at large angles, and the lack of marked predominance of violet at any angles. This characteristic of the curves follows from the fact that the points of maximum polarization correspond to very large angles.

XIV.

Experiments upon Silver.

Owing to the great kindness of Mr. Herbert G. Torrey, Assayer of the U. S. Assay Office, I was next able to make a series of observations upon molten silver. These experiments were the most satisfactory of any which were made in the course of the research. All of the sources of error which had existed in preceding cases were here eliminated. The surface was perfectly defined, it was accurately horizontal, and there were no variations in intensity from point to point. The results of the experiments are given in full.

30°		35°		40°		45°	
Left.	Right.	Left.	Right.	Left.	Right.	Left.	Right.
46.0	36.0	44.5	33.4	43.3	31.7	42.0	30.5
47.2	36.0	45.0	33.7	42.8	32.5	42.0	31.0
46.5	35.0	44.5	34.0	43.3	32.0	41.1	31.3
46.3	35.0	45.0	34.0	43.5	32.0	42.5	30.5
46.5	35.5						
46.5	35.5	44.75	33.8	43.72	32.05	41.9	30.8
$2w = 0°.82$		$2w = 78°.55$		$2w = 75°.27$		$2w = 72°.7$	
$p =$ 0.139		$p =$ 0.189		$p =$ 0.254		$p =$ 0.297	

50°		55°		60°		65°	
Left.	Right.	Left.	Right.	Left.	Right.	Left.	Right.
40.6	28.5	38.0	27.0	34.7	24.1	32.0	21.0
40.0	29.0	38.3	27.5	35.0	24.0	32.5	21.5
40.0	29.8	37.5	27.1	34.0	24.1	32.6	21.0
40.5	29.1	37.5	26.3	35.4	23.8	32.5	20.5
40.0	28.8	38.0	26.5	35.7	24.0	32.5	21.5
				34.5	24.0		
40.2	29.04	37.8	26.8	34.9	24.0	32.4	21.3
$2w = 69°.24$		$2w = 64°.6$		$2w = 58°.9$		$2w = 53°.7$	
$p =$ 0.354		$p =$ 0.429		$p =$ 0.517		$p =$ 0.592	

70°		75°		80°			
Left.	Right.	Left.	Right.	Left.	Right.		
30.0	20.0	27.0	16.5	24.1	13.5		
30.0	19.5	27.0	16.5	24.1	13.5		
29.6	19.9	27.0	16.5	24.2	14.0		
30.0	20.4	26.5	16.1	23.9	13.7		
30.5	19.5	27.0	16.4	24.0	13.9		
		26.5	15.5				
30.0	19.9	26.8	16.25	24.1	13.7		
$2w = 49^\circ.9$ $p =$ 0.644		$2w = 43^\circ.05$ $p =$ 0.731		$2w = 37^\circ.8$ $p =$ 0.789			

All of the previous observations had been subject to errors of unknown magnitude, aside from the errors of observation; and the results, while agreeing very closely with the calculated values for some angles, differed from them by considerable amounts at others. For example, the agreement for platinum at 80° was very close, while at 70° the difference was as large as .045. Similarly for uranium glass, the difference at 50° and 65° was quite large. Hence I did not consider the results given by the experiments upon uranium glass and platinum altogether trustworthy as accurate quantitative measurements. The experiments upon silver, however, were free from all possible error so far as I was able to discover, except the observational error. Mention has already been made of the fact that Violle had previously made a number of determinations of the same general nature upon silver. His results do not agree very closely with those given above, being uniformly larger. I am altogether unable to account for the uniformity in the excess of his values over those given by these experiments. His results are here inserted for the sake of comparison.

Angle.	Violle.	Millikan.
30	0.168	0.139
50	0.383	0.354
60	0.546	0.517
65	0.630	0.592
70	0.708	0.644
75	0.770	0.731
80	0.826	0.789

The application of Cauchy's formulæ to silver was made in the same way as in the case of platinum. For polished silver Quincke gives for the D line,

Prime angle of incidence, $A=72^\circ\ 10'$,
Prime azimuth, $H=41^\circ\ 40'$.
Formulæ (4) give $e=82^\circ\ 34'.3$, $\log\theta=0.4480$.

Formulæ (3), (2), and (1) then give

a	K^2	K'^2	$1-K^2$	$1-K'^2$	p
80	0.9735	0.8037	0.0265	0.1963	0.762
75	0.9606	0.7628	0.0394	0.2372	0.716
70	0.9482	0.7510	0.0518	0.2489	0.655
65	0.9361	0.7540	0.0639	0.2460	0.588
60	0.9250	0.7632	0.0750	0.2368	0.519
55	0.9136	0.7740	0.0864	0.2260	0.446
50	0.9033	0.7869	0.0967	0.2131	0.376
45	0.8937	0.7985	0.1063	0.2015	0.309
40	0.8847	0.8093	0.1153	0.1907	0.246
35	0.8767	0.8187	0.1233	0.1813	0.190
30	0.8695	0.8268	0.1305	0.1732	0.140

It will be noticed that the agreement between these quantities p and those given by my experiments is closer than for either the platinum or the uranium glass; the largest difference being at 80°, where it amounts to 0.027.

XV.

Experiments upon Gold and Iron.

Through the kindness again of Mr. Torrey and the Superintendent of the Subtreasury, I was permitted to make observations upon a pot of molten gold; but accuracy of work was impossible on account of (1) the rapidity with which I was obliged to work; (2) the lack of quiescence of the liquid surface; (3) the impossibility of excluding other light from the surface; and (4) the rapidity of oxidization of the molten gold. The results were therefore altogether untrustworthy as quantitative measurements. Hence no attempt was made to compare them with results given by Cauchy's formulæ. Molten iron was also made the subject of similar observations with equally unsatisfactory results.

XVI.

Discussion of Results.

The comparisons made between experimental determinations and calculated values are condensed in the following tables:—

Uranium glass.				Platinum.				Silver			
Angle.	p. obs.	p. calc.	Difference.	Angle.	p. obs.	p. calc.	Difference.	Angle.	p. obs.	p. calc.	Difference.
87½	0.358	0.351	0.007	80	0.829	0.834	−0.005	80	0.789	0.762	+0.027
85	0.293	0.315	−0.022	70	0.610	0.655	−0.045	75	0.731	0.716	+0.015
80	0.245	0.251	−0.006	60	0.481	0.492	−0.011	70	0.644	0.655	−0.011
75	0.191	0.206	−0.015	50	0.349	0.341	+0.008	65	0.592	0.588	+0.004
70	0.139	0.153	−0.014	40	0.191	0.216	−0.025	60	0.517	0.519	−0.002
65	0.098	0.125	−0.027	30	0.099	0.117	−0.018	55	0.429	0.446	−0.017
50	0.039	0.058	−0.019					50	0.354	0.376	−0.022
								45	0.297	0.309	−0.012
								40	0.254	0.246	+0.008
								35	9.189	0.190	−0.001
								30	0.139	0.140	−0.001

In view of the general agreement between the observed and calculated values, and in view of the further fact of the coloration of the images at large angles, so beautifully accounted for by the reflection theory, it may be considered that the phenomenon of polarization of light by emission has thus been quantitatively proven to be a phenomenon of reflection and refraction.

It will be remembered that the apparently insuperable objection to the explanation which Arago offered was that that explanation attributed to all of the surface molecules the property of emitting natural light, and gave as the entire cause of the polarization, the refraction of light which works its way up from a certain depth beneath the surface.

The above calculations were all made upon the assumption that *all* of the light emitted by the glowing body had undergone a refraction. Considering the closeness of agreement between the calculated and observed values, it is difficult to escape the conclusion that this assumption is correct, and that *no* particles whatever of the incandescent solid send out into the air natural light, save in the case in which the angle of emergence is zero. This simply means that all of the particles of the light-emitting body, *including* the so-called surface layers, lie within the denser medium, and beneath the plane at which reflection and refraction take place. This relieves the refraction theory of the causes of the phenomenon of its greatest difficulty: viz., the difficulty of conceiving that, in the case of an exceedingly opaque body like platinum, the uppermost molecules send out but a very small proportion of the whole light emitted. If we follow the explanation of Arago and Verdet, we are obliged by the results of this research to conclude that the emitted light originates almost entirely in molecules other than those of the uppermost layer. On the contrary, it seems much more reasonable to assume that in the case of such a body as platinum the light emitted is due mainly to this topmost layer, but that the reflection process takes place entirely *above* the platinum.

Quincke has shown that when light from an external source is reflected at the surface of a metal, the reflection does not take place in the geometrical plane between the two media, but rather takes place in the metal itself, the vibration penetrating for a certain depth into the denser medium. The converse is also doubtless true that the vibration originating in the metal is not reflected instantaneously at the surface of the rarer medium, but is reflected in the layer of air of finite thickness which borders upon the metal. Thus all light originating in the platinum, whether in the surface layer or the sub-surface layers, must undergo the process of reflection and refraction before it can emerge into the air.

Lastly, the calculated values were all obtained under the assumption that the optical constants of the metals are the same for high temperatures as for low; that is, that the reflecting properties of an incandescent metallic surface are precisely the same as the reflecting properties of a cold metallic surface. The closeness of agreement between the results given by this assumption and the facts as determined by experiment seems to warrant the conclusion, that the change in the optical properties of metals due to incandescence is *exceedingly slight;* a conclusion to which the somewhat inexact experiments of Grove upon the reflecting properties of incandescent platinum would also lead.

The results of the investigation may therefore be summarized as follows: —

(1) Experiments upon polarization by emission have been extended to a wider range of substances than had previously been investigated, and these substances have been classified with reference to their power of producing the phenomenon.

(2) The polarization of the light emitted by flourescent bodies has been, I believe for the first time, observed and measured.

(3) The difference in the color of the principal components of the light emanating at large angles from white-hot metals has been observed and explained. So far as I am able to discover, this fact had not been before known.

(4) Some experimental ground has been given for the conclusion that all light originating in an incandescent body, whether in the surface molecules or in the interior molecules, must suffer a reflection and refraction before actual emergence.

(5) The reflecting properties of metals have been shown to be but little, if at all, affected by the fact of incandescence.

(6) The phenomenon of polarization of light by emission has been shown conclusively to be a phenomenon of refraction, first, by the closeness of agreement between a large number of experimental and calculated quantities, and second, by the fact of the difference in the color of the images at large angles of emergence which finds complete explanation in the refraction theory.

In conclusion, I will add that this investigation was suggested to me by Professor Rood, and I wish here to express my thanks to him, and to Professor Hallock, and also to Professor A. A. Michelson, of Chicago University, for aid furnished during its progress. I am also under obligations to Herbert G. Torrey, Assayer of the U. S. Assay Office, who most kindly placed at my disposal large masses of molten gold and silver.

PHYSICAL LABORATORY OF COLUMBIA COLLEGE.